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The capture of a Σ^--hyperon without any visible interaction

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Summary

In a nuclear emulsion an event has been found which can be explained as a Σ^--hyperon coming to rest, interacting with a nucleus and giving a 0-prong star. The hyperon has been identified by mass determinations according to four different methods. The probability of Σ^--hyperons giving 0-prong stars is discussed.

Introduction

In the course of a systematic study of tracks in a nuclear emulsion an event was found which can be explained as a negative hyperon coming to rest in the emulsion and giving a star with no visible prongs in its interaction with a nucleus.

A few similar events have been found previously. Fry, Schneps, Snow, and Swami have observed three hyperons of this kind in an investigation of negative K-particles [1]. Their hyperons stop in the emulsion with an associated electron at the end of each of them. These electrons are the result of the atomic capture of the negative hyperons. Castagnoli, Cortini, and Manfredini reported at the Pisa conference 1955 two events [2]. The particles stop in the emulsion, one with an associated blob and the other with an electron. Accurate mass determinations have now been made definitely showing that the particles are hyperons. These particles and the particle described in this paper were reported together at the Rochester conference 1956 [3].

Experimental observations

The emulsion was exposed to the cosmic radiation at the Sardinian expedition 1953, flight No. 25, II PD. The type of emulsion is Ilford G5 on glass with a thickness of 600 μ. The plateau value of the blob density is 20 blobs/100 μ.

The hyperon track which ends in the emulsion is very flat. The residual range of the track is 5 cm in the emulsion in which it stops. The particle cannot be traced back to its origin. The position of the track in the emulsion is favourable for an accurate mass determination. All parts of the track which have been measured have been situated far from the surface (> 150 μ in the unprocessed emulsion) and far from the glass (> 100 μ). The distances to the edges of the plate have been so large that no disturbances depending on edge effects are possible. The quality of the emulsion has been tested by measurements and identification of long grey tracks crossing the hyperon track. No irregularities of importance for the identification have been found.

Table 1.

Method	Range interval (mm)	Mass (m_e)
I Residual range – mean track width (MTW)	$0 < R < 18$	2 205 ± 120
II Residual range – scattering	$0 < R < 10$	2 360 ± 300
III MTW – rate of change of MTW	$18 < R < 48$	2 645 ± 260
IV MTW – scattering	$28 < R < 48$	2 430 ± 210
	Mean value	2 318 ± 90

A careful inspection of the end of the hyperon track has been made. The emulsion is very clean at this point. No electron track can be seen and there does not seem to be any blob from a recoiling residue of the absorbing nucleus.

The mass determinations have been made according to four methods. The methods are listed in Table 1 which also includes the results of the different determinations.

I. Photo-metric determination of mean track width – residual range

The instrument used for the photo-metric measurements has been described by von Friesen and Kristiansson 1952 and by von Friesen and Stigmark 1954 [4, 5]. The mass is determined relative to protons. The calculations are made according to a least squares method described by Kristiansson 1954 [6]. The error quoted in the table includes errors in MTW of the hyperon and the comparison protons, straggling, and also an error from the irregularities of the emulsion. The last error originates in difficulties to find comparion protons near the hyperon where the MTW-level is exactly the same as in the hyperon track. This error has been discussed by Kristiansson in an earlier paper [6].

II. Scattering – residual range

The measurements of scattering were made according to the method of constant sagitta. The cell-size "scheme" used is calculated by Fay, Gottstein, and Hain [7]. The "scheme" for protons was chosen with a constant sagitta $\bar{D}_p = 0.5\ \mu$. The "noise" of the scattering measurements has been determined to 0.12 μ, thus giving a "signal-to-noise ratio" of approximately 4.

In first approximation the above-mentioned "scheme" may be used for particles of different masses. The relation between the mass M and the sagitta $\bar{D}$ for an unknown particle is

$$M = M_p \left(\frac{0.5}{\bar{D}} \right)^{2.33}.$$

This formula has been used in the calculation of the hyperon mass given in the table.

III. Mean track width – rate of change of mean track width

The hyperon track has been measured with the instrument described in connection with the first-mentioned mass determination. The measurements have been made relative to about 40 protons. The error quoted in the table is in accordance with the distribution of the protons. This method of particle identification will be discussed in a forthcoming paper [8].

IV. Mean track width – scattering

The measurements of mean track width are the same as in method III. The scattering of the track is determined according to Fowler's coordinate method with a cell-size of 200 μ [9]. The mass is determined relative to about 20 protons.

Discussion

From the measurements of the mass it can be seen that the particle is heavier than a proton but lighter than a deuteron. It has no visible secondary. Consequently the conclusion must be drawn that the particle is a negative hyperon, either a Σ^-- or a Ξ^--particle which interacts with a nucleus giving a 0-prong star.

The masses of the Σ^-- and Ξ^--particles are 2338 m_e and 2581 m_e respectively (Rochester conference 1956). The mean value of the mass determinations on the hyperon described in this paper is $2318 \pm 90\ m_e$. The result makes the assumption very plausible that the particle found is a Σ^--hyperon.

According to the Gell-Mann Pais selection rules assuming strong interaction between the hyperon and the nucleus the following reaction was proposed by Friedlander, Fujimoto, Keefe, and Menon for the Σ^--particle [10, 11].

$$\Sigma^- + P = \Lambda^\circ + N + Q \qquad Q = 79 \text{ MeV}.$$

If both the Λ°-particle and the neutron leave the nucleus most of the reaction energy disappears as kinetic energy. Goldsack and Lock assume an available mean excitation energy of the order of 20–30 MeV [12]. Such a small excitation energy will often lead to no visible interaction. If either the Λ°-particle or the neutron is absorbed the excitation energy will be higher, but also in this case the probability for a very small star is rather large depending on the neutron excess in the excited nucleus. Therefore it is to be expected that a large proportion of the negative hyperons just stop in the emulsion, without any visible secondary tracks.

Table 2 shows the prong number distribution for Σ^--stars which are identified fairly accurately. The table contains stars collected by Goldsack and Lock and also the 0-prong stars discussed in the introduction of this paper.

Table 2.

Number of prongs > 5 μ	0	1	2	3	4	5	6	7	8
Number of hyperon stars	6	8	1	–	1	1	–	1	–

As it is difficult to identify hyperons giving 0-prong stars, the number of these stars must be much underestimated in relation to the number of stars with visible prongs. Some of the 0-prong stars have been found in K^--particle studies, which makes it difficult to compare the figures directly.

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